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RENEWABLE FUELS RELATED SAFETY ISSUES USED FOR DOMESTIC PURPOSE IN THE SCOPE OF SUSTAINABLE DEVELOPMENT.

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Abstract

For domestic cooking purpose many fuel types have been used throughout the world, ranging from solid fuels to liquid to gas. Gaseous fuels are considered cleaner because of their inherent characteristics of low pollutant formation and emissions during handling and use. Nevertheless, from the viewpoint of sustainable development, other safety properties are important, such as flammability limits, auto ignition temperature, specific gravity, vapour pressure, toxicity and flash point. This paper discusses several aspects of cooking fuel safety, considering traditional clean fuels such as LPG, natural gas and kerosene, and non-traditional and/or renewable fuels such as producer gases, DME, biosyngas, ethanol and ethanol-gel. The main aspects are related to transport and distribution system, product poisoning, equipment and use. Gaseous fuels are the preferred solution to replace unhealthy traditional fuels. As renewable options are still under development, LPG is often considered the short term solution to deliver modern energy on a global scale for cooking applications.

Keywords- *biosyngas, fuels, non-traditional gas, sustainable development*

1. Introduction

Several fuel types have been used for cooking throughout the world, ranging from solid to liquid to gas. Gaseous fuels, followed by light liquid fuels, are considered the cleaner varieties because of their inherent characteristics with low pollutant formation and emissions during handling and use. Traditionally, gaseous fuels are fossil fuels derived from petroleum or natural gas, and their usage cannot be considered sustainable in the long term.

The combustion characteristics of gaseous fuels are suitable for cooking purposes because of the ease and safety of operation and combustion control. These features have allowed for the development of high efficiency and low pollutant emission stoves. In addition, they favour ease of global distribution through either pipeline or bottles. At the present time, natural gas, liquefied petroleum gas (LPG) and kerosene are the clean fuels favoured internationally for domestic cooking. Replacing traditional fuels reduces deforestation, protects users' health by reducing smoke and soot, and allows time for women and children to pursue education and other productive activities. Future substitutes for clean fossil fuels for domestic cooking may include biogas, biosyngas, dimethyl ether (DME), ethanol and ethanol-gel [1].

Table 1 shows the typical composition and characteristics of gaseous fuels and Table 2 presents the main combustion characteristics of fuels and gases dealt with in this paper.

2. Traditional clean fuels for cooking (LPG, natural gas, and kerosene)

2.1. Natural gas

Natural gas, like petroleum and LPG, is a fossil fuel, and it can be found in underground gas fields or associated with petroleum. Its main constituent is methane. Since natural gas cannot be liquefied at atmospheric temperatures, its transport and circulation is managed through pipelines. Town gas was a mixture produced from coal gasification by means of several different conversion processes and was the first gas distributed in cities. It originated in the middle of the 18th century and was used exclusively for lighting purposes [2]. During the 19th century, its popularity soared and remained high until the first half of the 20th century when it was gradually replaced by natural gas.

2.2. LPG

The history of LPG since its invention in 1912 is closely aligned with its use for cooking and lighting. Named ''gasol'' by its discoverer, Walter O. Snelling, this unique product has 4 times the heating capacity of coal gas and produces a brighter light than either natural gas or coal gas. Because of its high heat content, consistent temperature and cleanness, LPG began to be used as a replacement for coal and wood, the traditional cooking fuels. The term ''LPG'' is an abbreviation of liquefied petroleum gas also known as ''LP gas'' or ''bottled gas''. An accurate term would be ''LPGs'' or ''LP gases'' since the name includes a family of light hydrocarbon compounds of varying molecular structures, the main two ingredients being propane (C_3H_8) and butane (C_4H_{10})[3]. Commercially, LPG generally consists of a varying blend of these two gases and of unsaturated derivatives.

These hydrocarbon compounds exist in nature as gases, but are liquefied for simplicity and efficiency of storage and transportation. Several hundred volume units of vapour are condensed into a single volume unit of liquid when subjected to slight pressure or refrigeration. When depressurized before burning, the liquid expands and reverts to its natural gaseous state. It is this unique ability to be both a liquid and a gas in the same container that accounts for its efficiency in transportation, storage and use. Today, hundreds of millions of people throughout the world rely on LPG for cooking, because of its portability, cleanness, convenience and safety are the same reasons why it became popular nearly 100 years ago.

2.3. Kerosene

Presently, the familiar liquid cooking fuel, known as paraffin or kerosene is a hydrocarbon mix, similar to aviation turbine (jet) fuel, with a primary distillation between 185 and 240ºC, placing it between petrol and diesel. The tremendous growth of commercial aviation triggered a dramatic increase of paraffin production in refineries. The marketed product is a jet fuel more or less hydrogenated to exclude impurities and reduce odour, making indoor use suitable. The history of paraffin or kerosene is older than that of natural gas as it belongs to the first generation of petroleum products [4].

Table 1. Typical composition and combustion characteristics of gaseous fuels for cooking [5]

Typical composition (% volume)	**LPG**	DME	**Natural gas**	Biogas	**Biosyngas**	**Producer gas**
H_2					51.8	14.7
CO					45.1	16.6
CO_2			0.1	45	2.7	18.4
N_2			1.4			50.6
CH_4 (methane)			91.8	55	0.4	0.3
C_2H_6 (ethane)	0.5		5.6			
C_3H_8 (propane)	34.3		0.9			
C_3H_6 (propylene)	24.4					
C_4H_{10} (butene)	28.2		0.1			
C_4H_8 (butene)	12.6					
C_2H_6O (dimethyl ether)		99.5				
Low calorific value (kJ/m^3)	87990	58437	37590	21850	12603	5160
Specific gravity to air	1.6	1.6	0.6	0.99	0.52	1.07
Air/gas stoichiometric (m^3/m^3)	25.5	19.1	9.9	5.2	3.4	1.1

Table 2. Main combustion characteristics of gases & liquids of fuels for cooking

Name of fuel	Auto ignition Temp. (ºC)	Specific gravity to air	Lower inflammability limit in air (% vol.)	Upper inflammability limit in air (% vol.)	Boiling Point	Flash Point (Liquid fuel) (ºC)
Methane	540	0.55	5.3	15	-162.3	
Ethane	515	1.04	3.0	12.5	-88	
Propane	450	1.53	2.2	9.5	-42.2	
Propylene	460	1.45	2.4	10.3	-48	
Butane	405	2.01	1.9	8.5	-0.6	
Butene	385	1.94	1.6	9.3	3.0	
Hydrogen	400	0.07	4.0	75	-252.7	
Carbon monoxide	605	0.97	12.5	74	-192	
DME	235	1.6	3.4	27	-23.7	
Ethanol	365	1.59	4.3	19	78	15
Methano	385	1.11	7.3	36	65	16

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Kero sene	250	5.0	0.8	5.4	185 to 206	40 to 55

3. Renewable fuels for cooking (biogas, producer gas, DME, and ethanol)

3.1. Biogas

Biogas results from the anaerobic digestion of organic wastes (sewage, manure, organic matter). It is composed of methane and carbon dioxide, including traces of sulphurous and other gases. Bio-digesters have been built and exploited in rural areas of India, China and Nepal. Biodigesters permit storage capacity, allowing for equilibrium between production and demand for consumption. Biogas is an authentic sustainable fuel because it makes use of organic wastes.

3.2. Producer gas

Producer gas is a combination of gases from biomass gasification, a process differing from coal gasification. Wood, agricultural wastes and charcoal are used to generate this form of gas, usually on a relatively small scale for local small-industry applications [6]. It is a combination of hydrogen, carbon monoxide, carbon dioxide and a considerable concentration of nitrogen owing to the air used as a gasification agent. Because of these characteristics, it has a low heating value and its storage is impracticable. Thus, it must be consumed as soon as it is generated, a complication for domestic use.

3.3. DME

Dimethyl ether (CH_3-O-CH_3) is a clear liquid which boils at -25ºC, similar to LPG. Other properties make it comparable to propane and butane. Therefore, the storage and handling technologies of LPG are applicable to DME.

DME is currently employed in spray paints, agricultural chemicals and cosmetics, and also as a propellant alternative to freons. Creating DME from stranded deposits of natural gas is an attractive and economical way to liquefy natural gas for simplification of transport and storage. China is developing a process to make DME from coal, which would turn its large natural coal resources into an easily transportable and cleaner fuel. It plans to build an 830,000 t/year DME factory, with DME cost much lower than that of synthetic diesel (Fischer-Tropsch diesel) on an equal energy basis [Longbao et al., 2002]. DME has been proposed as an alternative to liquefied natural gas (LNG), which has to be refrigerated at cryogenic temperatures for liquefaction, or as a substitute to diesel fuel owing to its excellent performance in diesel engines with lower particulate matter emissions.

4. Safety issues regarding clean fuels for cooking

4.1. Transport and distribution system

4.1.1. Liquefied gases

Safety and risk issues for clean hydrocarbon fuels have to be managed at several levels beginning with the supply and distribution system. LPG requires a specific distribution system apart from solid or other liquid fuels because it is stored and transported in pressure vessels. Although the source of LPG supply may be the same refinery or terminal from which other products are distributed, the equipment, storage tanks, trucks, rail wagons and the appliances themselves are uniquely designed for LPG. This ensures that equipment cannot be modified to accept other fuels, thus providing an additional level of safety and control. LPG is readily portable, meaning it can be stored and transported virtually anywhere in containers of various sizes. Throughout the developing world, LPG is distributed in cylinders or ‘‘bottles’’ ranging from 5 to 15 kg. Generally, they are filled at dedicated and controlled facilities where a strict safety policy is enforced, allowing only legal cylinders to be used and filled to the proper level. These cylinders are typically owned by the fuel supplier, but in some countries the customer is the owner. In the latter case, it is difficult to enforce safety practices since the cylinder may not come back to the expert facility for inspection and repair if needed.

Unethical and unlicensed operators have a tendency to ignore safety standards and practices. Caution must be taken to ensure the removal and destruction of damaged or unusable cylinders. Some unscrupulous operators have been known to take parts of unusable cylinders, weld them together and put a cylinder back in service. Such practices are not only violations of international standards, but also a definite danger to people and property.

Care must be taken to ensure that containers designed for only butane are not filled with propane because of the higher vapour pressure of propane. On the other hand, propane containers may be used to contain butane. Cylinders properly manufactured have a data plate that identifies the design parameters.

Unlike liquid fuels that can be transported and stored in non-dedicated containers, LPG equipment is designed solely for LPG usage. This may come at an economic penalty for those who wish to transport several fuels in a common truck or store various fuels in a non-dedicated container. However, dedicated equipment prevents deliberate or inadvertent mixing of fuels, the results of which can be dangerous.

The greatest risk at distribution (or refill) facilities is fire. An unintended release of LPG that finds its way to an ignition source can result in a severe blaze, leading to property damage and/or bodily harm, and, rarely but possibly, explosion. Some jurisdictions now favour mounding of tanks or installing them underground, avoiding storage explosion risk. The simple practice of prohibiting any kind of flame, cigarette lighter or flammable material from a facility is significant in precluding the danger of fire.

Sound design and construction that respect international regulations, safe operating procedures, trained operators, and a fire suppression system are essential for a sufficiently safe refill/distribution facility. Another factor is the enforcement of applicable policies and laws by local authorities, including a permit to operate the facility. Shortage of funds, inadequate regulations, lack of trained inspectors and corruption are common problems in many countries that compromise an effective risk management and safety programme.

4.1.2. Gases distributed by pipelines

Gases not liquefiable at ambient temperature must be transported and distributed by pipelines. These days, natural gas is dispersed to homes and commercial consumers throughout the world. Safety issues related to distribution are the supplier's responsibility. Generally private- or state-owned, they receive a concession for gas distribution and commercialization from the government [7]. This is a monopolistic activity, like electricity distribution, regulated by law and technical standards for quality and safety guarantees.

However, the effective safety depends on the capacity of the supervisory department. The supplier's responsibility ceases, in general, at the consumer's ''gate''. The piping from this ''gate'' to the consumption points becomes the consumer's responsibility. Pipes made of durable materials (copper, carbon steel) demand little or no maintenance.

Attention must be paid to old installations, hidden in walls or below the ground, limiting visual access for inspection.

The safety records of natural gas are notable where it has been used for several years or where it has replaced a town gas used by regular consumers. Special care must be taken in developing countries, where the supply has begun recently.

4.1.3. Liquid fuels and liquid-gel fuels

Kerosene is easy to store and transport because it does not require the use of specific tools, making it uncomplicated to store in any container and marketable in very small quantities. This flexibility has its benefits, but inconveniences as well, the greatest being the risk of mixing with other hydrocarbons. With a lighter hydrocarbon there could be a risk of explosion when the product is heated for combustion.

With a heavier hydrocarbon, there is poor combustion with production of smoke and tar. The frequent cause of dangerous mixing is not the lack of caution (even if a very hazardous mix of petrol and kerosene can occur from time to time), but fraud. Products for domestic use enjoy generally a much lower duty rate than road transport fuels, in many countries encouraging smuggling, which increases the risks dramatically.

Hydrated ethanol is distributed in small containers (0.5-5 litres) made from plastic (polyethylene is most common). Owing to the containers' flexibility and the ease of handling, bottled ethanol has been the cause of several domestic accidents

5.1.4. Illegal practices in distribution

Since cylinders are expensive to purchase, pirate operators tend to steal them. Needless to mention, they overlook the inspection for damage or certification of the cylinders, over-fill or under-fill them, put abandoned cylinders back in operation, and lack the skills to operate trucks and facilities safely.

The tax on domestic (cooking) gases is low in many countries to encourage their use in preference to traditional fuels [8]. But, because LPG is an excellent automotive fuel and considering the higher taxes on fuels for automotive use, the fear is that attempts will be made to use a cooking gas cylinder in a vehicle, or transfer the fuel from a cooking gas cylinder to that of a vehicle. This is a dangerous practice and also an illegal one because it cheats the government of its rightful tax revenue.

Using subsidized kerosene as an automotive fuel is also an illegal practice, but there are no specific risks during a transfer. If kerosene is used in a petrol engine it can cause severe damage to the engine.

4.2. Lighting, extinction, flame stability and interchangeability of gases

Unlike biomass fuels that require time to reach an acceptable cooking temperature, LPGs and other gases are instantaneously hot. When not in use, the fuel supply is simply turned off, conserving precious supplies and eliminating the danger of hot glowing coals, a source of many burn accidents mainly suffered by children. Flame stability is an important characteristic for fuel gases. Burners for stoves are usually pre-aerated: combustible mixture is formed in the space preceding the point where the flame occurs. Gas burners must be designed to accommodate exclusive gas characteristics. If the flame speed is high, the flame will become too elevated and extinguish. If the speed is low, the flame returns to the aeration channel and light-back occurs, also extinguishing the flame. In conditions where there is not sufficient air, an incomplete combustion starts as a yellow tip burning on hydrocarbon gases. Kerosene, ethanol and ethanol-gel are easier to ignite than biomass fuels and can quickly produce an acceptable cooking temperature. By cutting off access to air, a kerosene fire can be extinguished quickly and the cooking surface will not remain hot for very long. Kerosene and others liquid fuels are in an intermediate position between instant on-off fuel gases and traditional solid fuels.

4.3. Flammability limits

Three things are necessary for combustion: oxygen, fuel, and a source of ignition. The ratio of fuel to air (flammability range) in order to have a combustible mixture with LPG is very narrow, meaning too much or too little fuel mixed with air will not support combustion. Considering typical LPG compositions (propane and butane), its flammability range is 2-9.5 % by volume in air. Natural gas and biogas range from 5 to 15 % and DME from 3.4 to 27 %. Manufactured gases such as biosyngas drepresent the largest flammability range, 4-75 % by volume in air, caused by the presence of hydrogen and carbon monoxide. Besides the flammability range, the lower limit is a crucial factor indicating the concentration where the risk of fire and explosion are possible. LPG has a lower flammability risk than natural gas. LPG's greater density slows its capacity to disperse quickly and it therefore has a lower risk compared to natural gas. High-density LPG (also DME) leakages have a tendency to accumulate closer to the ground whereas the lower-density natural gas rises. This LPG characteristic is particularly hazardous for underground piping inside buildings.

The auto-ignition temperature for most hydrocarbon gases ranges from 400 to 500ºC. The few exceptions are methane's higher temperature of 540ºC, DME's reported low of 235ºC and kerosene vapours at 250ºC. Evaluating the fire risk with hot surfaces is very important in case of leakage. Kerosene vapours have a narrow range and ignite at a low concentration, 0.8-5.4 % volume in air, compared to ethanol, whose range is 4.3-19 %. Kerosene is also high in density, thus preventing quick dispersion. The potential of vapour generation from liquid fuels is evaluated from their flash point. The flash point of ethanol is 15ºC and it has a higher capacity to generate vapour than kerosene. The flash point of kerosene is estimated at 40-50ºC, but it is a mixture of several hydrocarbons and its flash point may vary beyond its typical limits. Flash point is controlled by formulation in the refineries and strongly regulated to improve safety for aeronautical proposes.

4.4. Odorization

In its normal state, LPG is odourless. Odorants are added to provide ample notice to correct any problem before a leak becomes hazardous. The odorants are distinct, strong smelling chemical compounds selected on the basis of human sensitivity to their scent. Very minute quantities are needed for detection. Normally, the odour is injected at or near the source of supply so as to taint the entire distribution chain. Odourless LPG is employed in selected specialized industrial and commercial applications, but should never be accessible to the public. Paraffin has an odour, but owing to its common practice of storage in open containers this odour is always present and is not an alert to a potential hazard.

4.5. Health issues

Any source of energy in a successful sustainable development scheme must satisfy the basic requirements of being environmentally friendly, affordable, promoting economic growth, and being socially acceptable and accessible to a large part of the population. The importance of cooking fuels because of their intrinsic importance in sustaining livelihood itself requires an analysis of their role in the sustainability criteria. The health issue is a high priority and is well documented in many studies [9]. Using clean cooking fuels can dramatically lead to improved health conditions, particularly for women, small children and senior citizens. Traditional solid fuels emit a large number of pollutants that lead to premature births and low birth-weight of children, acute respiratory infections, chronic lung disease, heart disease, and eye conditions. A child is two to three times more prone to infection if exposed to smoke in the home. Children under five account for 56 % of total deaths from indoor air pollution. Households relying on wood, dung and crop waste are especially vulnerable. Compared to solid fuels, the pollutant emissions from gaseous fuels are extraordinarily lower. LPG and natural gas are low-polluting, and laboratory tests have shown emissions still lower for DME. Light liquid fuels, mainly the oxygenated fuels such as ethanol, also burn with low emissions comparable to those from gaseous fuels[10].

7. Conclusions

Gaseous fuels such as LPG and natural gas have been proven through international, long-term experience to be safe fuels for cooking. If handled properly kerosene is also safe, but not comparable to gaseous fuels. They have good properties for storage, handling and utilisation, but these traditional clean fuels are fossil fuels. Renewable fuels for long-term sustainable development still have limitations or are under technical development. Biogas is a good option for cooking: safe, non-toxic, and derived from a renewable source. Yet it remains infeasible for urban and metropolitan regions. Nevertheless, it has been proven to be a sustainable cooking fuel, according to the experiences of Chinese and Indian users. DME is a promising fuel, and could be developed through synthesis routes from biomass. Biosyngas is an attractive renewable gaseous fuel, because its technical basis is well known and further development is feasible. However, it presents a safety concern due to the presence of carbon monoxide in its composition. Nevertheless, town gas, with the same property, was used for almost a century in the past. Ethanol-gel is another attractive fuel for cooking falling in the scope of sustainable development. It is safe, with low-polluting emissions, and can be made from several renewable feedstocks. It is not as versatile as gaseous fuels, because burners and equipment need to be improved, yet Malawi's experience with using it for cooking is encouraging.

Gaseous fuels are the preferred solution to replace unhealthy traditional fuels. LPG is available everywhere. As renewable options are still under development, it is often considered the short-term solution to deliver modern energy on a global scale.

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